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EFFECT OF VARIOUS CARBURETOR THROTTLE SETTINGS ON THE FLOW CHARACTERISTICS AT THE OUTLET OF A SUPERCHARGER INLET ELBOW

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ADVANCE RESTRICTED REPORT

EFFECT OF VARIOUS CARBURETOR THROTTLE SETTINGS ON THE FLOW CHARACTERISTICS AT THE OUTLET OF A SUPERCHARGER INLET ELBOW

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SUMMARY

An investigation has been conducted to determine the effect of varying the carburetor throttle settings on the flow characteristics at the outlet of the supercharger inlet elbow. Air-flow tests were made at carburetor throttle settings of full open, and 15°, 30°, and 45° closed.

The carburetor throttle setting had an appreciable effect on the turbulence and the velocity distribution at the inlet to the supercharger. For a limited range of carburetor throttle settings, small changes in the throttle setting may cause large changes in the velocity distribution at the elbow outlet. The results of this investigation are limited to carburetor-elbow combinations in which the carburetor has a single throttle valve that closes when the downstream edge moves toward the inside of the elbow.

INTRODUCTION

The demand for increasing the power and the economy of aircraft engines has caused an intensive study to improve the fuel distribution and the charge-air distribution in radial engines. Besides producing a rough-running engine, nonuniform fuel and charge-air distributions cause some cylinders to develop higher temperatures than others. The detrimental effects due to this condition have been enumerated in references 1 and 2. A discussion of the magnitude of the resulting loss in power and economy has been presented in reference 3; in some installations, for example, a 50-percent reduction in the pressure drop required for cooling at rated power could be obtained by eliminating the unequal fuel and charge-air distribution. At some cruising conditions (reference 3) the fuel consumption could be decreased 20 percent by the same improvement.

Numerous NACA investigations to improve the fuel and charge-air distribution in various engines have demonstrated that the trend and the magnitude of the spread of the distribution is greatly affected by the angular position of the carburetor throttle. Critical conditions have been encountered in which moving the throttle through only a few degrees will change an acceptable distribution to one at which operation is impossible. This effect may be caused by the resulting changes in the velocity distribution and the turbulence of the air flow at the face of the supercharger impeller.

The present investigation conducted at the Cleveland laboratory of the NACA during the summer of 1944 was therefore made to determine the order of magnitude of the variations in the flow characteristics at the outlet of a supercharger inlet elbow. The carburetor used had a single throttle valve that closed when the downstream side moved toward the inside of the elbow. The velocity distribution of the air was measured at the carburetor and elbow-assembly discharge to determine whether the angular position of the throttle has enough effect on the flow at the exit of the supercharger inlet elbow to warrant an extensive investigation. Tuft studies were also made at the elbow outlet to estimate the relative turbulence.

APPARATUS

The duct-component test rig used for the flow investigation of the carburetor and the inlet elbow is shown in figure 1. Air was supplied at a static pressure of 40 inches of water above atmospheric pressure and was discharged to the atmosphere. The weight flow of air was regulated by a single butterfly-type control throttle. A 16-mesh screen was inserted 20 diameters downstream from the valve to remove any disturbances created by it. A calibrated pitot-static tube installed at the reference station (fig. 1(a)) 20 diameters downstream of the screen was used to measure the weight flow. The head of the tube was located $1\frac{3}{8}$ inches from the duct wall and a thermocouple was placed diametrically opposite to measure the temperature at this section. Standard Prandtl-type pitot-static tubes with a head length of $1\frac{3}{4}$ inches made of stainless-steel tubing 1/8-inch outside diameter were used for all survey measurements, as well as for reference measurements. Throughout the entire distance from the control throttle to 3 feet beyond the reference station, the inside diameter of the duct was $12\frac{1}{8}$ inches.

The reference pitot-static tube was calibrated for the range of flow by comparing the weight flow obtained with the reference tube with that obtained from six equally spaced radial surveys at the reference station. The precision of the weight flow determined was within ±1 percent.

Flow tests were made on an assembly consisting of an injection carburetor, a carburetor-to-elbow adapter, and a typical inlet elbow. The geometry of the flow path of this inlet elbow differs only slightly from the geometry of elbows for most radial engines; the results therefore should be directly applicable to any radial engine on which the same type of carburetor is used. The test elbow was modified by cutting off the diffuser and the impeller front shroud 1/2 inch upstream from the plane of the impeller face and by fastening a 1/2-inch flange faired to a 7.388-inch inside diameter on the downstream side to the elbow by means of hook bolts pivoted to the ribs on the outside of the elbow.

Bosses were mounted on the outlet pipe to place the heads of the survey tubes in a plane coincident with the location of the front face of the impeller in a normal engine installation. The location of the bosses was such that four surveys parallel to the plane of the bend and 1/2 and $2\frac{1}{8}$ inches on each side of the elbow center line (fig. 1(a)) could be taken. Air temperatures at the elbow outlet were measured with a thermocouple installed 6 inches downstream from the survey station to eliminate flow interference at the survey station. Any resulting errors in temperature measurements were negligible on an absolute-temperature basis because the temperature change through the entire setup was only in the order of 2° F.

At the reference station an NACA micromanometer was used to measure the dynamic pressure to 0.01 inch of alcohol. The reference-tube static pressures, as well as the static and the dynamic pressures of the survey tubes, were read on U-tubes in inches of water and the atmospheric pressure, corrected to 32° F, was measured on a microbarograph. Temperature measurements were obtained from iron-constantan thermocouples by means of a self-balancing potentiometer.

In the tuft studies made for the purpose of studying flow characteristics, the outlet duct was replaced by one made of Plexiglas in which some woolen tufts were mounted on wires 1/2 inch downstream from the elbow outlet and others were glued to the inside periphery in four parallel rings 1/2, $2\frac{1}{2}$, $4\frac{1}{2}$, and $6\frac{1}{2}$ inches downstream from the elbow outlet.

METHOD OF TESTS AND CALCULATIONS

Before each survey the carburetor throttle was set and locked in place and the weight flow of air through the system was adjusted by the control throttle to obtain a reference static pressure of approximately 30 inches of water above atmospheric pressure.

Tests were run at carburetor throttle settings of full open, and 15°, 30°, and 45° closed; "full open" refers to the position of the carburetor butterfly valve when parallel to the center line of the inlet duct immediately preceding the carburetor (fig. 1(a)). All angular settings were made with this position as a reference or 0°. The A and the C surveys were taken simultaneously as were the B and the D surveys. Values of static and dynamic pressures indicated by the reference tube and the two survey tubes, the barometric pressure, and the temperatures obtained from thermocouples located at the reference station and 6 inches downstream from the survey station were recorded. When a complete set of measurements had been made, the survey tubes were set for the next point. After sufficient time had elapsed to overcome the lag in the pressure leads, the next set of measurements was taken.

Tuft studies were made for each of the carburetor throttle settings by taking right-quarter and left-quarter photographs of the Plexiglas duct at an angle of 45° from the plane of the bend of the elbow. Taking two photographs from positions 90° apart eliminated the possibility of showing the tufts in a vertical position on the photograph when the tufts were inclined along the line of sight.

Compressibility was not taken into account in the computations. Because the weight flow varied slightly with time, the velocity at each point of the survey was corrected by the ratio of the average reference velocity of the entire run to the reference velocity for that point. From the average density of the two simultaneous surveys, the cross-sectional area of the elbow outlet at the survey stations, and the weight flow, the average velocity for each two surveys was calculated.

RESULTS AND DISCUSSION

The results of the present investigation are applicable only to installations in which the carburetor has a single throttle valve that closes when the downstream edge moves toward the inside of the elbow. The velocity distributions obtained for the various throttle positions are presented as the ratio of the velocity at a given point along the traverse V to the average velocity of the two simultaneous surveys V_{av} plotted against the ratio of the distance of that point from the inside wall of the duct l to the total length of traverse of that survey L. Photographs taken under the same test conditions are also presented to show the flow characteristics obtained in the tuft studies.

At the full-open carburetor throttle setting (fig. 2) the velocity reaches a maximum near the inside wall of the elbow, decreases at a fairly uniform rate for approximately two-thirds of the distance across the outlet, and tends to increase slightly for the rest of the distance. Separation and backflow near the inside of the bend are shown by survey B. The corresponding tuft photographs (fig. 3) confirm these flow characteristics and the blur caused by the tufts shows considerable turbulence. Even with potential flow, the highest velocity will occur near the inside wall of any elbow outlet. The elbow used in these tests has a high rate of curvature and thus a high velocity near the inside wall at the elbow outlet.

At a throttle setting of 15° (fig. 4) the general trend of velocity distribution obtained for the full-open position was observed except that the peak value of V/V_{av} is higher and there is a tendency toward irregularity in the curves near the outside of the bend. The photographs (fig. 5) show that the turbulence has increased and is carried farther downstream. Slight secondary flow occurs near the inside of the bend. Curves obtained for a 30° throttle setting (fig. 6) are also similar to those for the full-open position. When the throttle setting was changed from 15° to 30°, however, the maximum value of V/V_{av} was reduced and the negative slopes of the curves were decreased. Although the tuft studies for the two settings appear to be similar (cf figs. 5 and 7), the relative degree of turbulence is probably greater at 30° than at 15° because the oscillation of the tufts seems to have the same magnitude at both settings even with the reduced air weight flow at 30°.

Moving the throttle from 30° to 45° caused the most pronounced change in velocity profile of any of the previous throttle changes. The curves for a 45° throttle setting presented in figure 8 have become almost horizontal over most of the traverse and the B and the C surveys, which are near the side walls (see fig. 1(a)), are slightly lower than surveys A and D near the center of the elbow outlet. This marked change in the velocity profile indicates the possibility of a critical range of throttle settings between 30° and 45°. Tuft studies at the 45° throttle setting (fig. 9) are not noticeably different from those at the 30° setting. The relative turbulence has probably increased but its effect on the oscillations of the tufts is counterbalanced by the opposite effect of decreased mass flow. In fact, the equalization of the velocity profile strongly indicates a large increase in the relative turbulence.

A possible explanation of the observed effects of the throttle on the flow at the elbow outlet can be given with the aid of figure 1(a). When the carburetor throttle is full open, the difference in velocities between the inside and the outside of the elbow is entirely due to the pressure gradient developed by the elbow. Thus figure 2, which shows the velocity distribution at the full-open throttle position, can be used as an approximation of the flow at the outlet without the carburetor, because this velocity distribution is changed very little by removal of the carburetor. When the throttle is partly closed, the resulting alteration in the flow passages causes two effects on the flow. One effect is the difference in velocity across the duct, and the other is the development of turbulence. The throttle divides the available flow area into regions A and B (see fig. 1(a)) in such a manner that the flow area is convergent in A and divergent in B. As a result of this configuration the velocity at the discharge of region A will be high, whereas that at the discharge of region B will be relatively low. This condition will tend to augment the high velocity that is inherently produced at the inside of the elbow. Even at very small values of θ (fig. 1(a)), separation will occur at the leading edge of the throttle and the resulting flow will be turbulent. Additional turbulence will be caused by the unequal velocities issuing from regions A and B at the trailing edge of the throttle. The turbulence thus caused is comparatively small at large throttle openings, but as the throttle is closed the flow becomes more and more turbulent. When the throttle is almost closed, the divergence of the flow area becomes so great that separation occurs in this space and another source of turbulence is developed. On the one hand, a high-velocity flow emerging from section A at the inside of the bend tends to augment the high velocity flow at the inside of the elbow. On the other hand, the interchange of energy promoted by the turbulence tends to equalize the velocity of the flow at the outlet of the elbow.

In this particular installation the velocity effect is predominate at a throttle closure of 15°, as shown by the fact that the velocity near the inside wall of the elbow outlet is much greater at the throttle setting of 15° (fig. 4) than at the full-open position (fig. 2). At the 30° throttle setting (fig. 6), the high velocity near the inside wall of the elbow outlet is lower than the corresponding velocity at the 15° throttle setting. Inasmuch as these curves are similar to those of figure 2, the velocity effects introduced by the throttle are almost exactly counterbalanced by the turbulence effects. At a throttle setting of 45°, the curves of figure 8 show that the turbulence effects have increased to such an extent that almost complete equalization of the flow velocity has occurred at the elbow outlet.

Even with uniform fuel distribution at the impeller inlet, the fuel and charge-air distributions would be considerably changed by varying the carburetor throttle setting. The impeller blades, the diffuser vanes, the collector, and the outlet ducting on a radial engine will tend to act as vanes and thus segregate the flow into individual elements. Although the magnitude of this uneven mixture distribution may be slightly reduced or increased, the nonuniformity will be in part transmitted to the cylinders. Actually, the fuel distribution at the impeller inlet will probably not be uniform. When the fuel is injected ahead of the impeller, it must be transported by entrainment in the air stream and thus will be affected by the turbulence and the velocity distribution of the flow. The centrifugal forces developed by the curvilinear motion of the air stream combined with the effect of gravity tends to cause the fuel to move toward the outside of the elbow. Any fuel deposited on the sides of the passage will also tend to accumulate at the outside of the elbow.

Other tests of fuel and charge-air distribution in radial engines have shown that for a small range of throttle positions very marked changes in flow are observed for small angular throttle variations, just as marked changes in flow distribution were observed in the present tests when the carburetor throttle is closed from 30° to 45°. Flow distortion caused by the supercharger inlet elbow and the carburetor will therefore have a considerable effect on the mixture distribution in certain ranges of carburetor throttle setting.

SUMMARY OF RESULTS

The results of flow and tuft studies of a typical supercharger inlet elbow and carburetor at varying throttle angles are as follows:

1. The distortion at the outlet of the supercharger inlet elbow first increased to a maximum and subsequently decreased as the carburetor throttle was closed.

2. The greatest variation in the velocity distortion occurred when the throttle position was changed from 30° to 45° closed.

3. The turbulence in the flow continuously increased as the carburetor throttle was closed from the full-open position.

CONCLUSION

The effect of the carburetor throttle setting on the flow characteristics at the outlet of the supercharger inlet elbow is of such importance that this effect should be considered in fuel and charge-air distribution problems.

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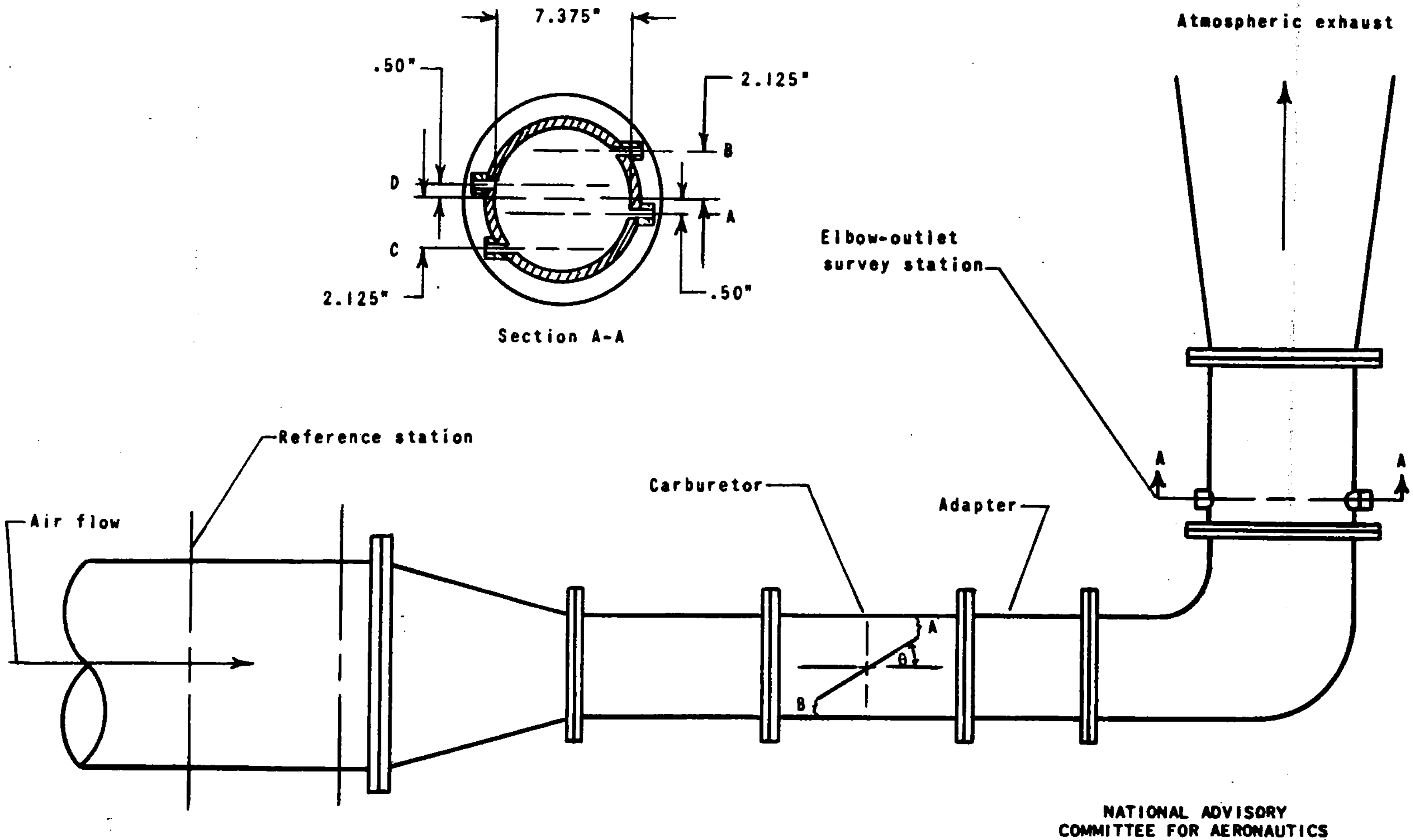
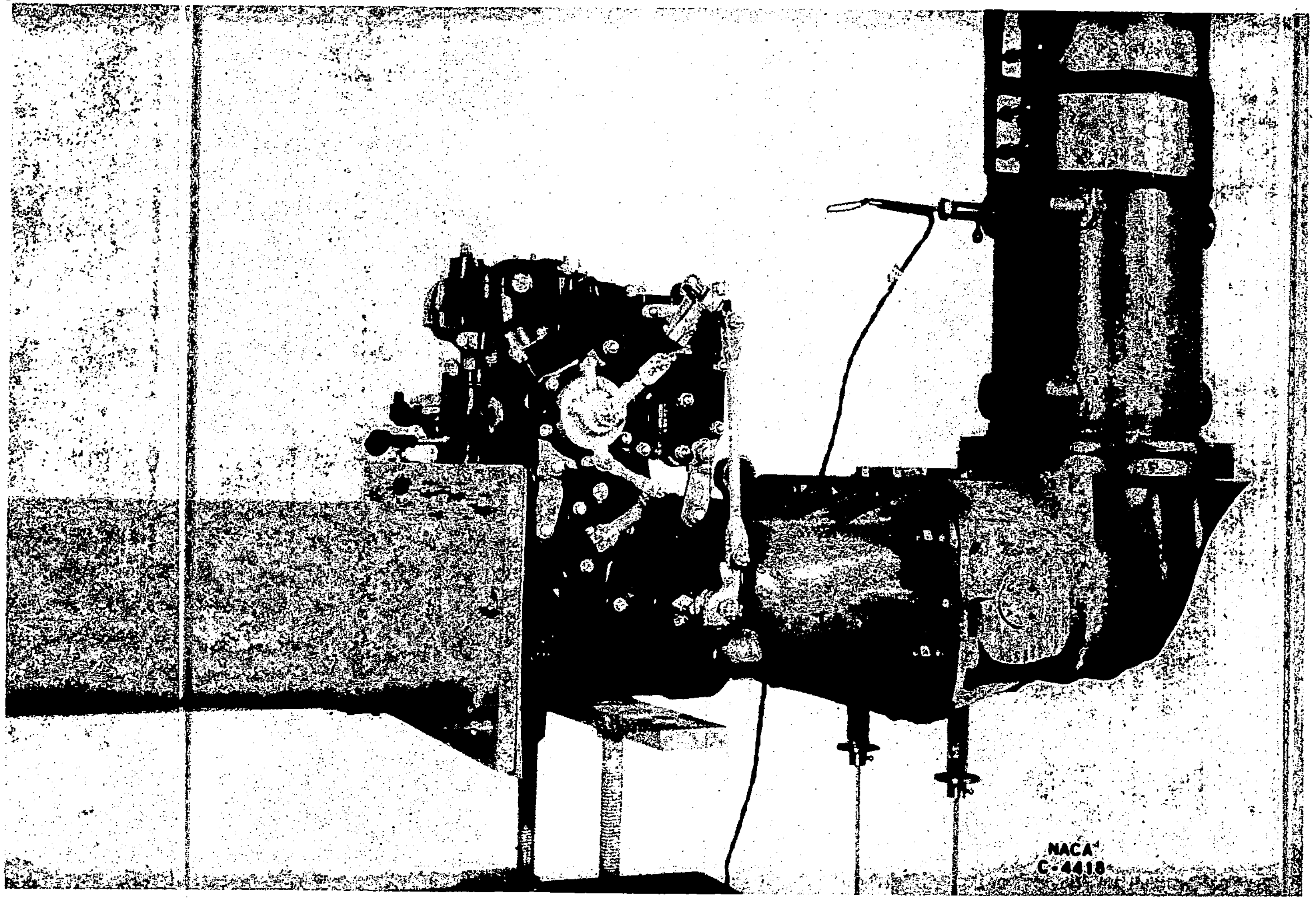


(a) Diagram of setup.

Figure 1. - Duct-component test rig used in flow tests of a supercharger inlet elbow with carburetor and adapter.



(b) Close-up view of setup.

Figure 1. - Concluded. Duct-component test rig used in flow tests of a supercharger inlet elbow with carburetor and adapter.

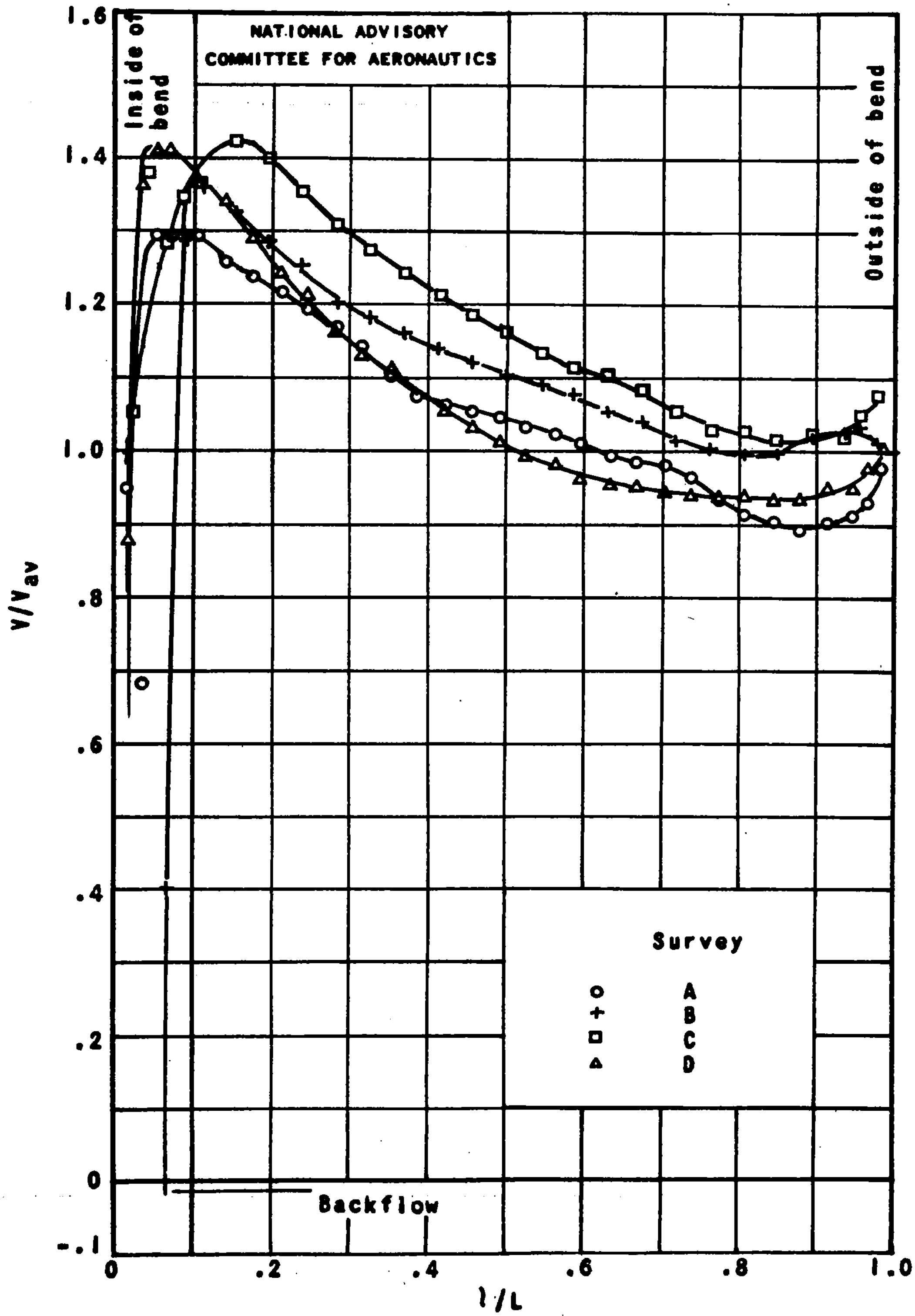
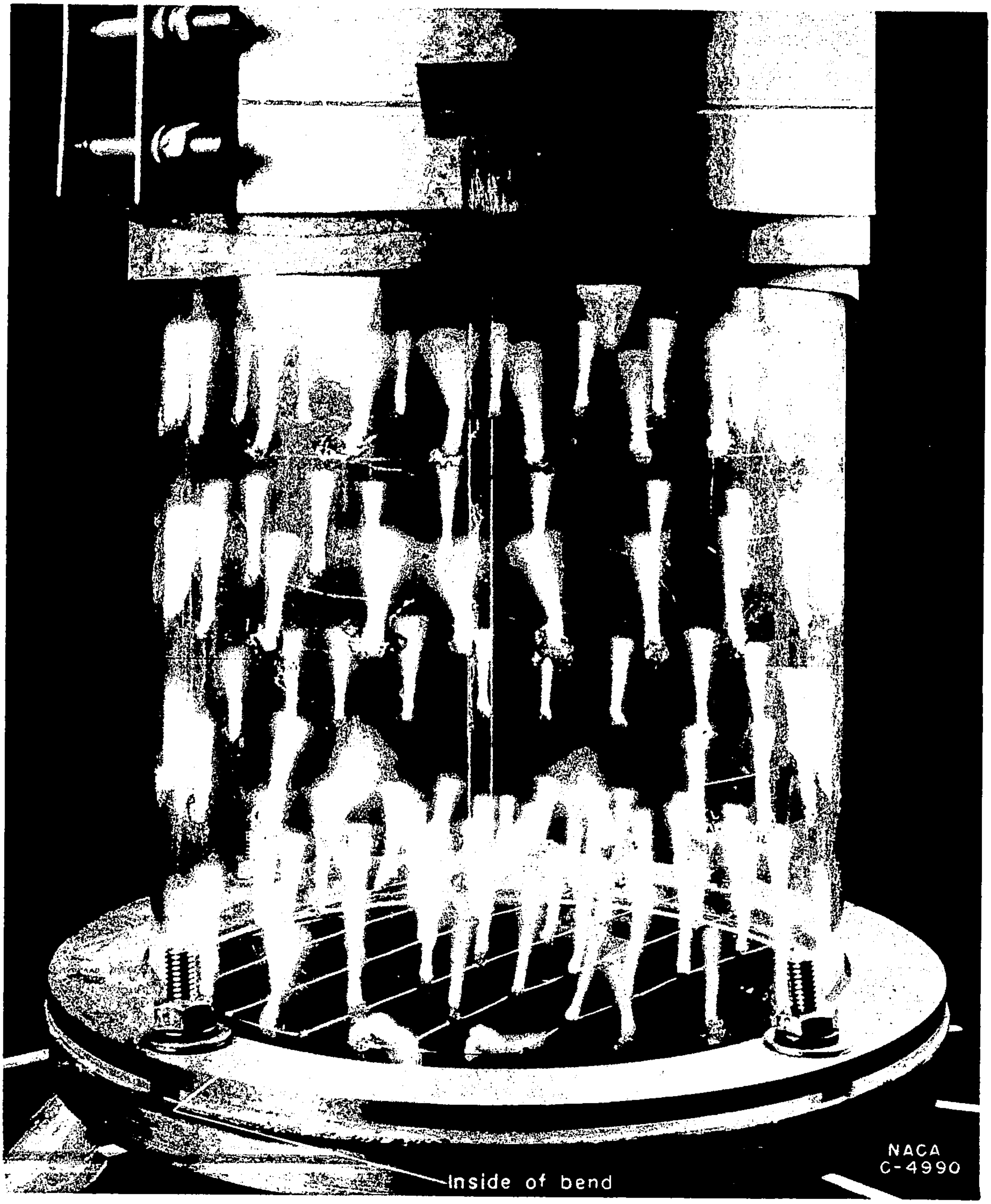
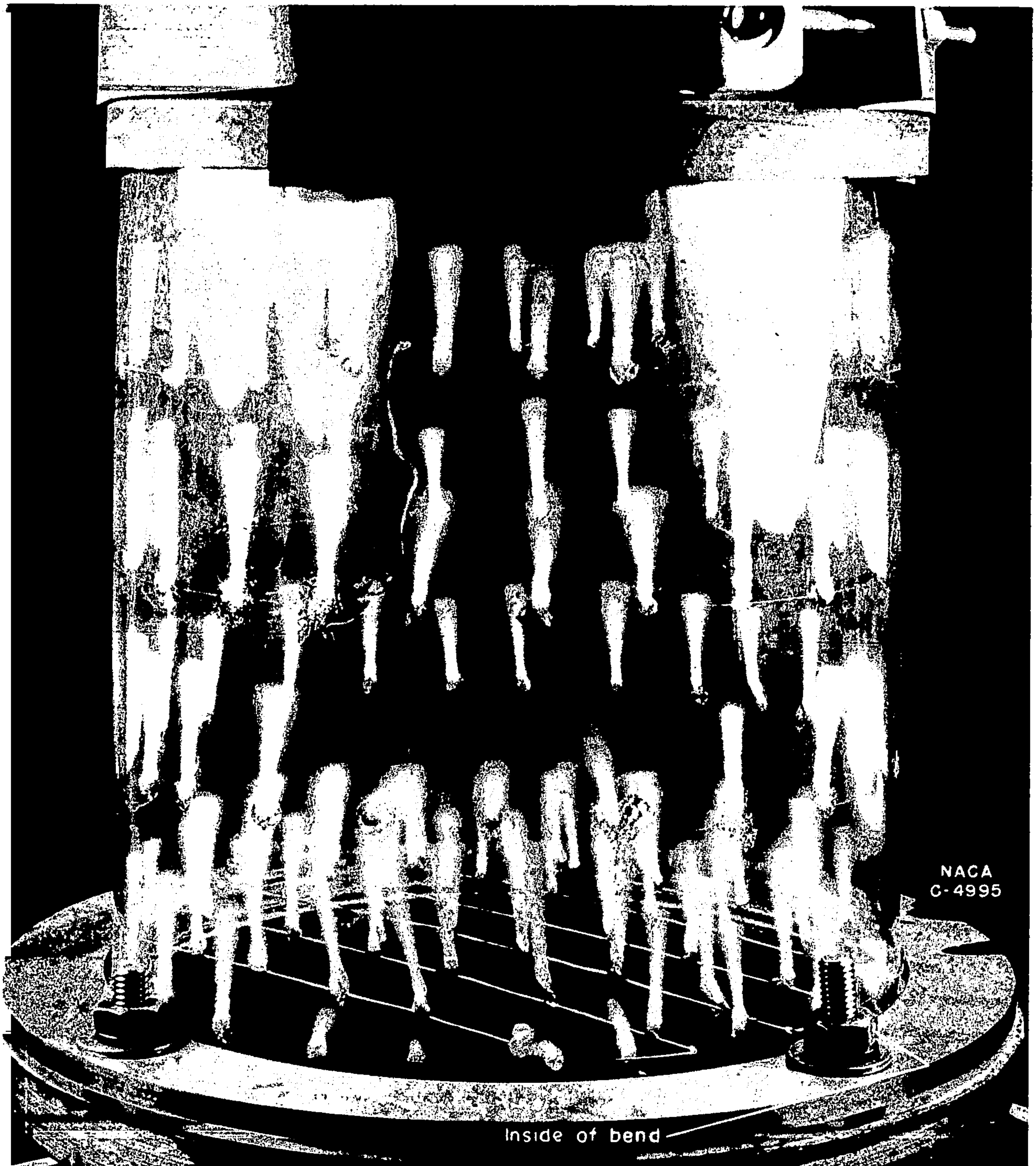


Figure 2. - Velocity profiles at the outlet of the supercharger inlet elbow with a carburetor throttle setting of full open.



(a) Right-quarter view.

Figure 3. - Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of full open.



(b) Left-quarter view.

Figure 3. - Concluded. Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of full open.

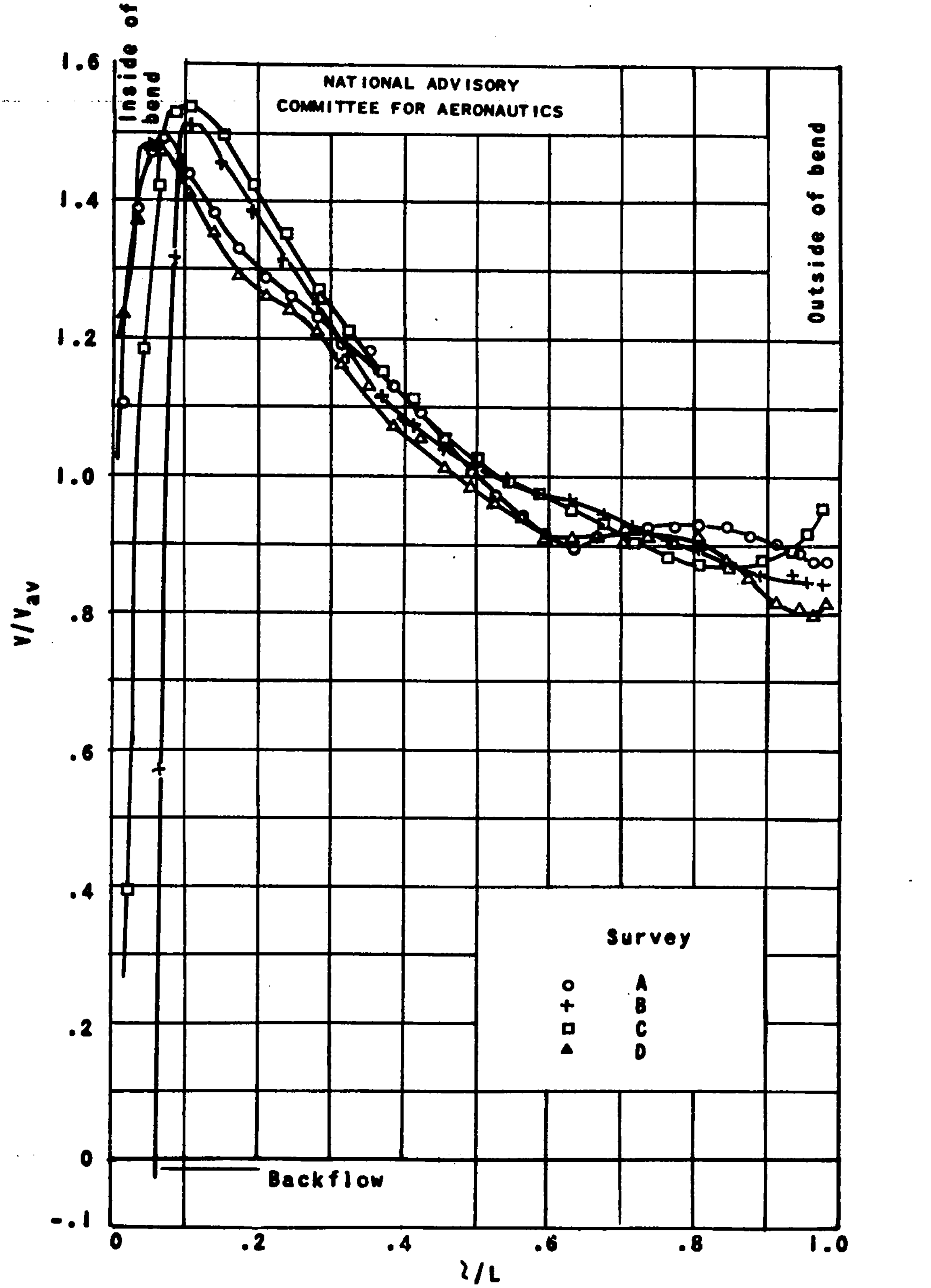
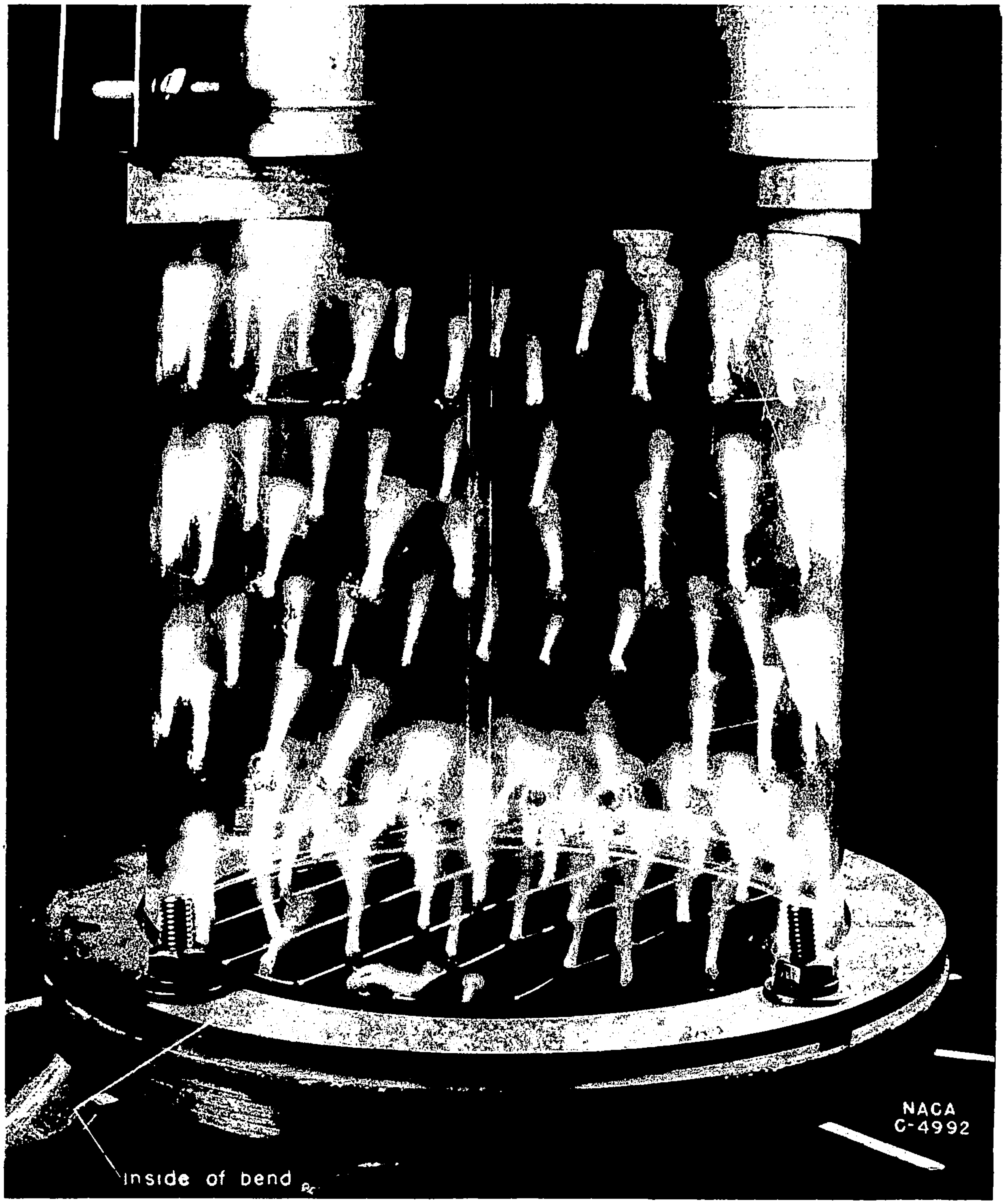
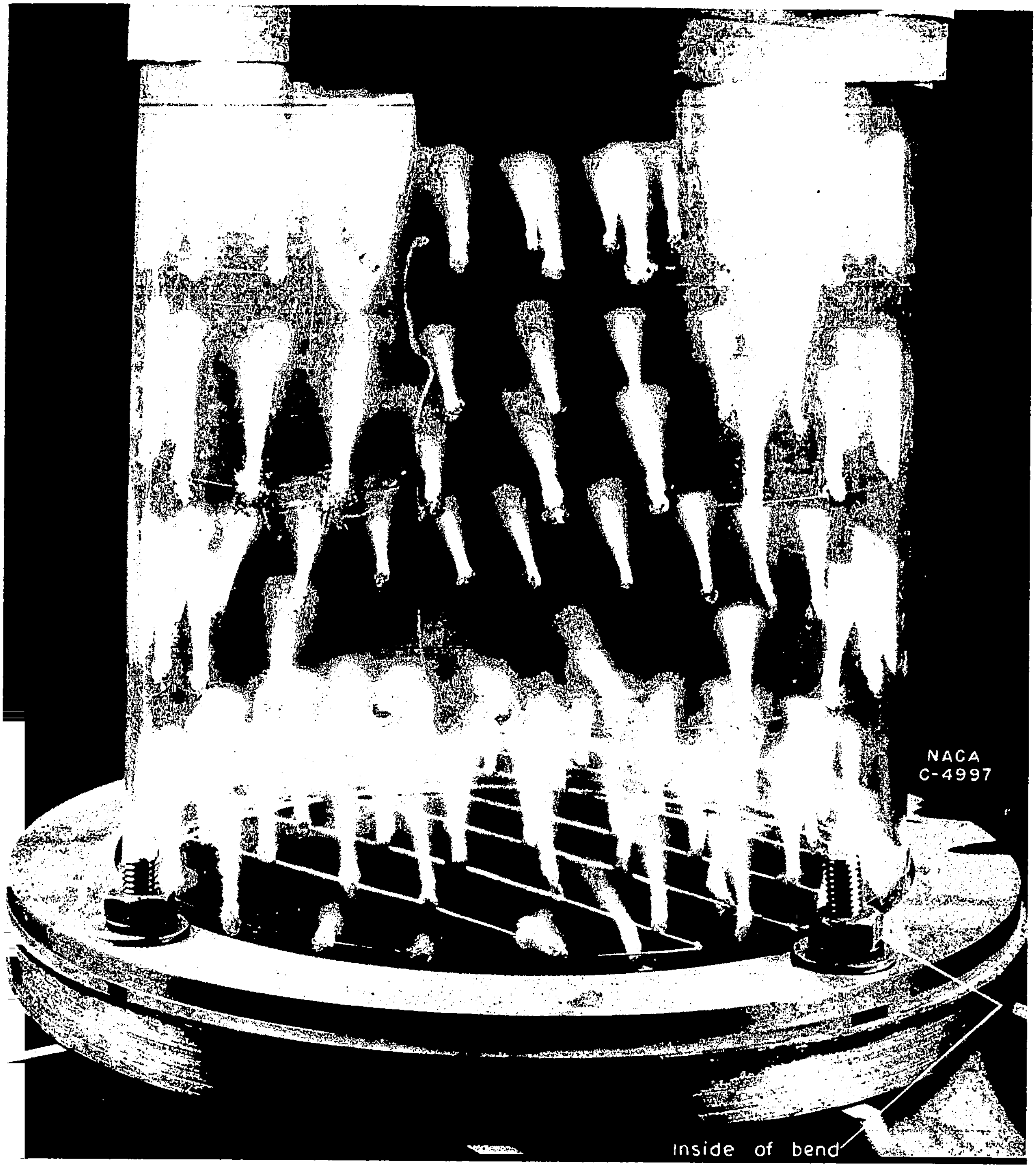


Figure 4. - Velocity profiles at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 15° closed.



(a) Right-quarter view.

Figure 5. - Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 15° closed.



(b) Left-quarter view.

Figure 5. - Concluded. Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 15° closed.

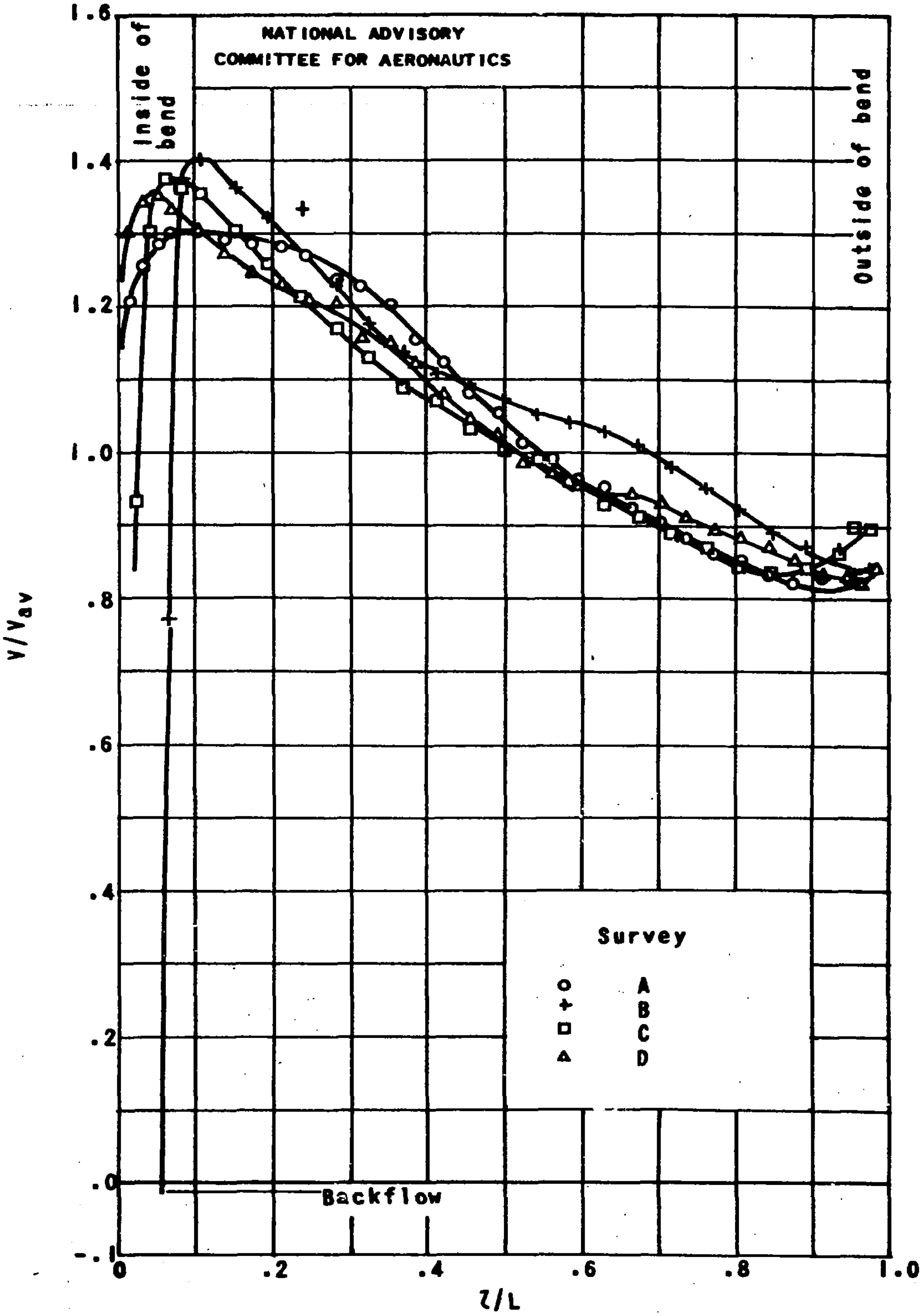
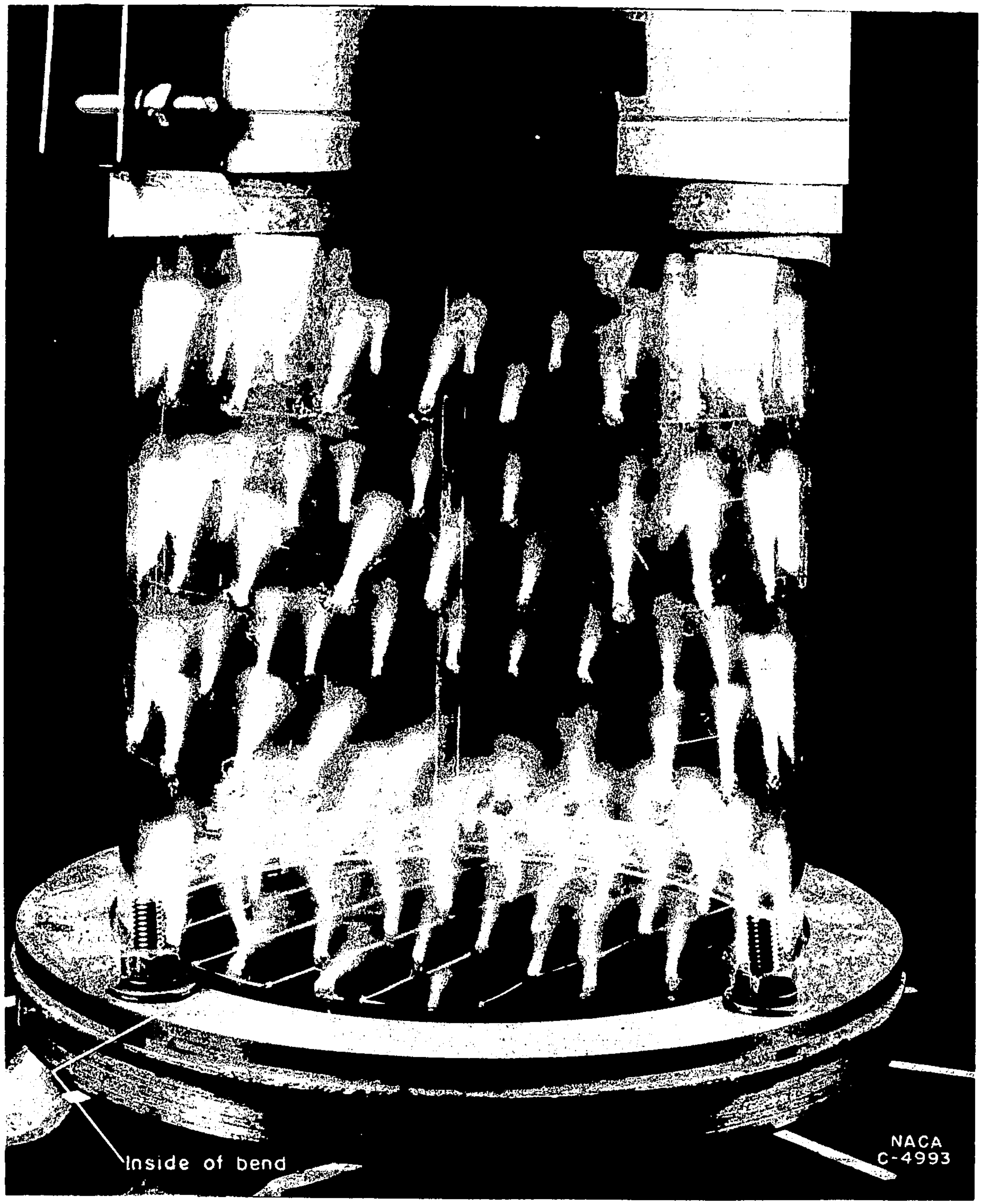
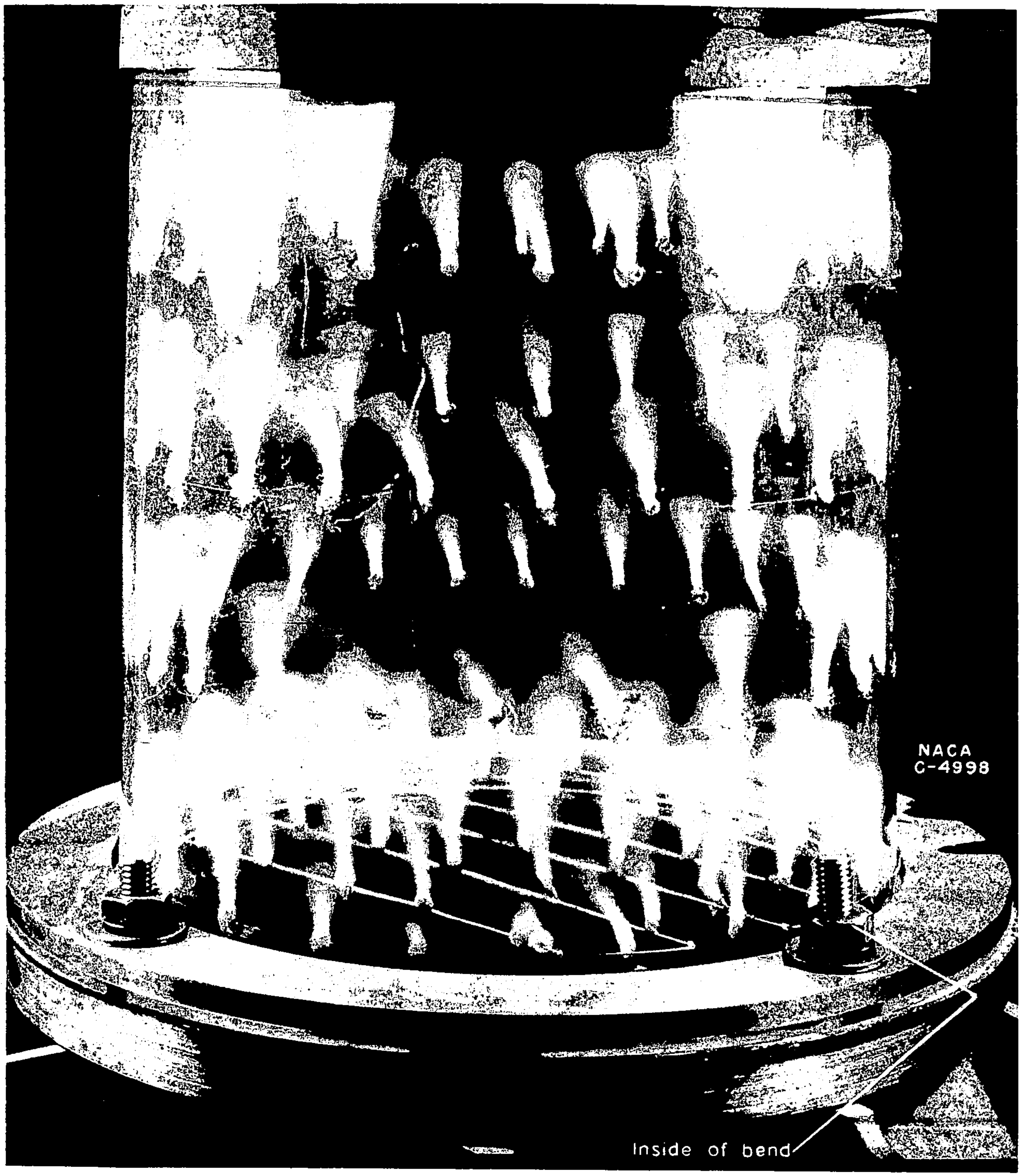


Figure 6. - Velocity profiles at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 30° closed.



(a) Right-quarter view.

Figure 7. - Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 30° closed.



(b) Left-quarter view.

Figure 7. - Concluded. Tuft studies at the outlet of a supercharger inlet elbow with a carburetor throttle setting of 30° closed.

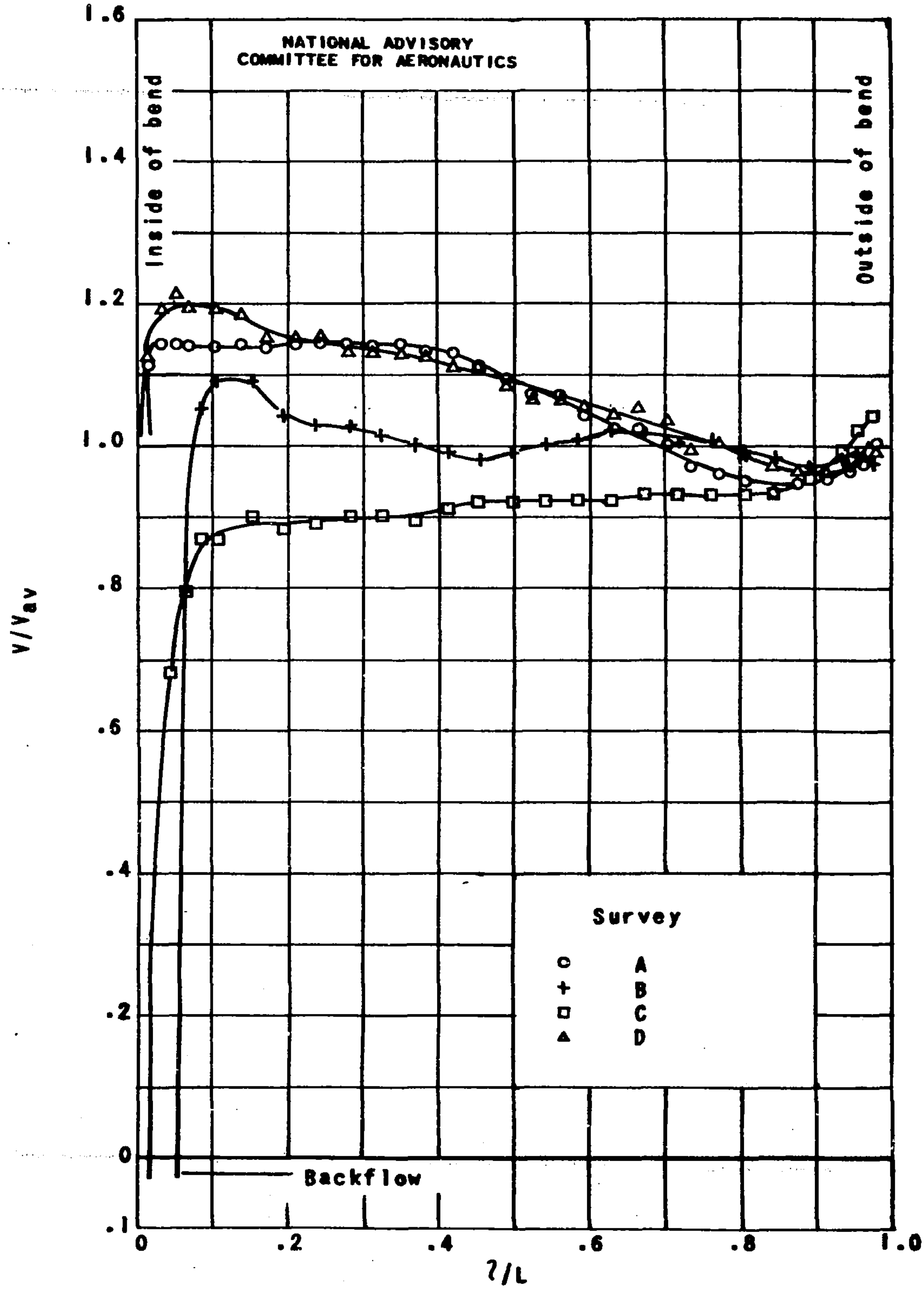
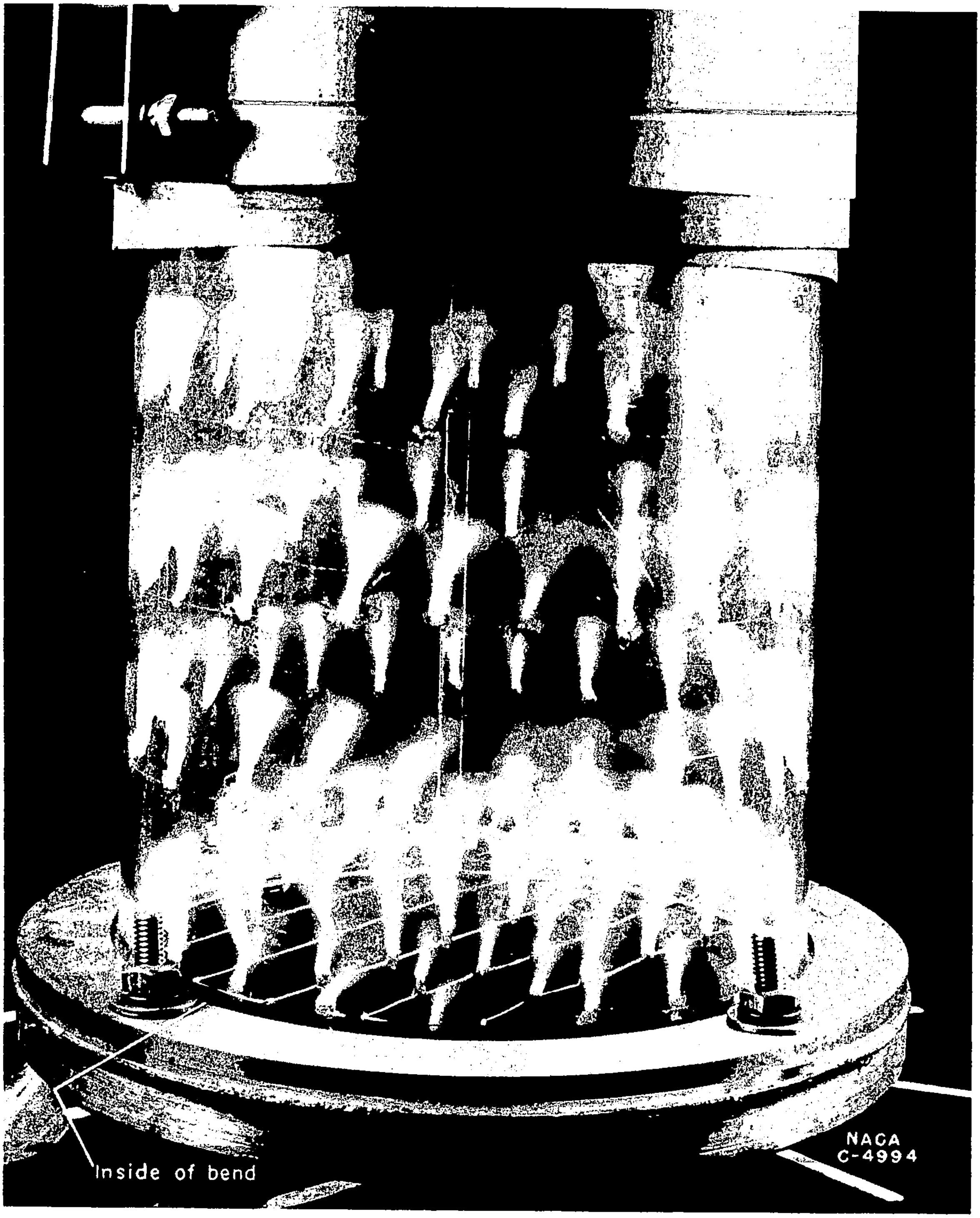
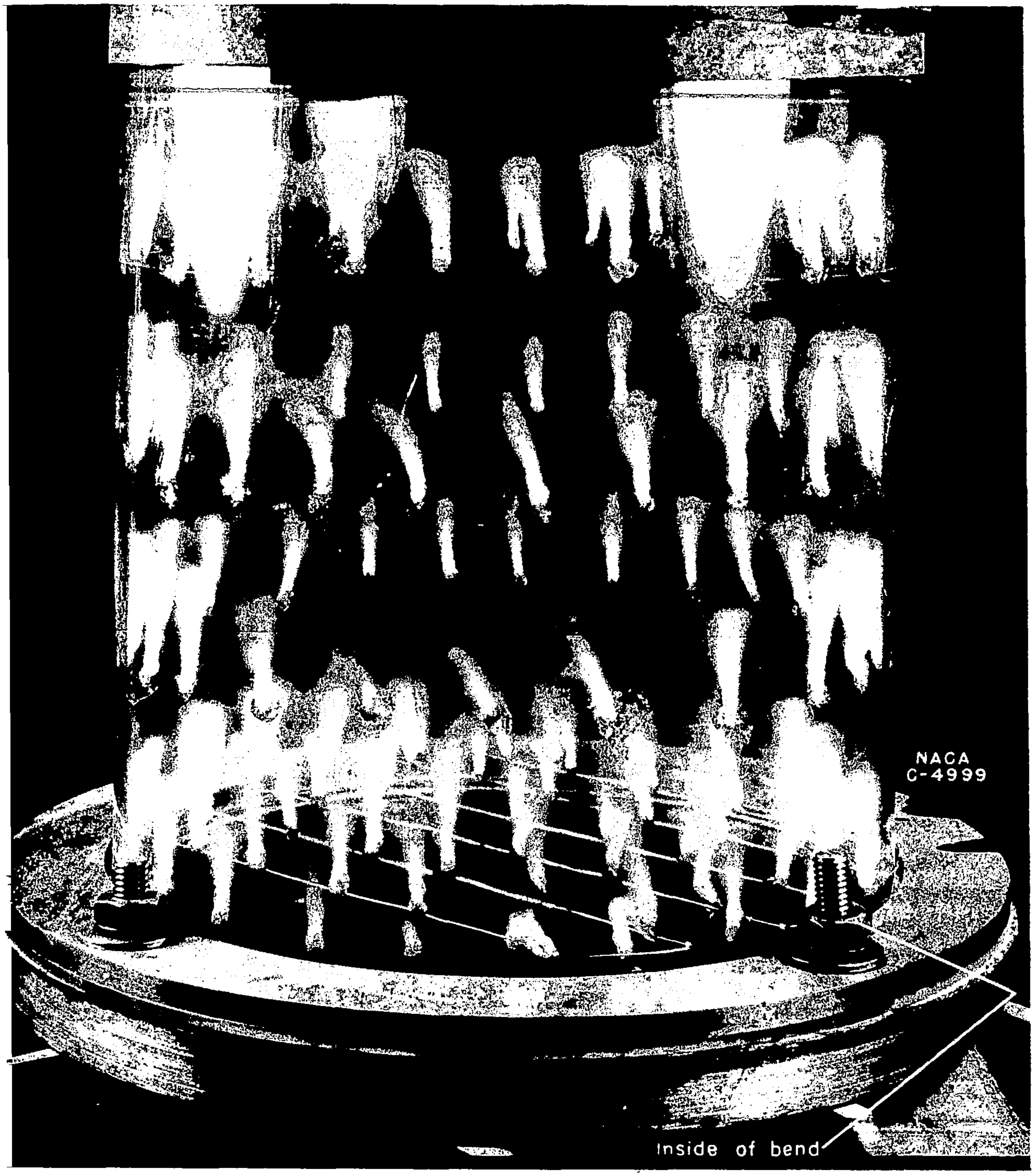


Figure 8. - Velocity profiles at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 45° closed.



(a) Right-quarter view.

Figure 9. - Tuft studies at the outlet of the supercharger inlet elbow with a carburetor throttle setting of 45° closed.



(b) Left-quarter view.

Figure 9. - Concluded. Tuft studies at the outlet of a supercharger inlet elbow with a carburetor throttle setting of 45^{o} closed.